

Small-signal Analysis of Darlington Pair
To determine the effective small signal resistance from B to E junction.

$$r_{e2} = \frac{26mV}{I_{E2}}$$

Looking into the base of transistor Q2

$$r_{in(Base)2} = \beta_2 r_{e2}$$

$$r_{e1} = \frac{26mV}{I_{E1}}$$

$$I_{E1} = \frac{I_{E2}}{\beta_2}$$

$$r_{e2} = (\beta_2 + 1) \frac{I_{E2}}{I_{E1}}$$

$$\Rightarrow \frac{I_{E2}}{I_{E1}} = \beta_2$$

$$r_{e1} = \beta_2 \left(\frac{26mV}{I_{E2}} \right)$$

Now,

$$r_{in DP} = \beta_1 r_{e1} + \beta_2 r_{e2}$$

$$= \beta_1 \beta_2 \left(\frac{26mV}{I_{E2}} \right)$$

$$r_{in DP} = \beta_1 (\beta_2 + 1) r_{in(Base)2}$$

It is the effective resistance looking into the base of Q1 across the

effective small signal input resistance

composite base to emitter terminal.
 $r_{in DP}$ is the effective resistance of small signal effect of Darlington pair

$$r_{in DP} = \beta_1 (\beta_2 + 1) r_{e2}$$

$$= \beta_1 (\beta_2 + 1) r_{e2}$$

$$r_{e(DP)} = \frac{r_{in DP}}{\beta_{DP}}$$

When the load is connected at the output of the Darlington pair configuration then the total input resistance to the follower circuit is,

$$r_{in} = r_{in DP} + R_{OP}$$

Methed of coupling/Types of Multistage Amplifier

1. R-C coupled Amplifier
2. Transformer coupled Amplifier
3. Direct coupled Amplifier

Chapter: 2

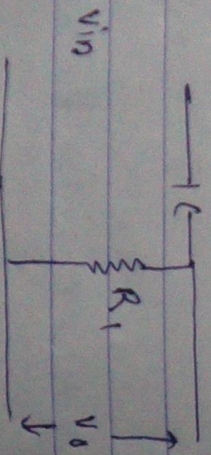
frequency Response of the coupled Amplifier.

→ Curve drawn between voltage gain & signal frequency response - Performance Analysis.

→ In order to know the uniformity of the designed amplifier.

→ frequency characteristics divided: Midband & upper frequency.

low frequency Response:-



In the low freq region ie below midband,

$$T_1 = R_1 C_1$$

Current through CR1

$$I_1 = \frac{V_{in}}{R_1 - jX_1} \quad , \text{ capacitive reactance,}$$

$$\text{O/p voltage gain } V_0 = I_1 R_1$$

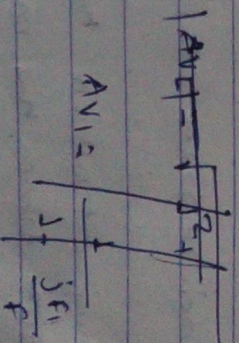
$$= \frac{V_{in}}{R_1 - jX_1} \times R_1$$

$$\therefore \frac{V_0}{V_{in}} = \frac{R_1}{R_1 - jX_1}$$

$$A_{V1} = \frac{V_0}{V_{in}} = \frac{1}{1 - \frac{j}{\omega R_1 C_1}}$$

$$= \frac{1}{1 - \frac{j f_1}{f}} \quad ; \text{ where } f_1 = \frac{1}{2\pi R_1 C_1}$$

= cut off freq.



$$|A_{vul}| = \frac{1}{\sqrt{1 + \left(\frac{f}{f_p}\right)^2}}$$

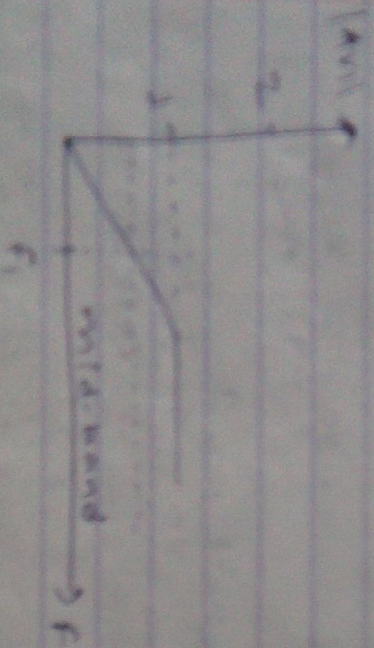
$$B: \tan^{-1}\left(\frac{f}{f_p}\right)$$

Condition:

at $f = f_1$, $|A_{vul}| = \frac{1}{\sqrt{2}} \approx 0.707$

at $f = 0$, $|A_{vul}| = 0$

at $f = \infty$, $|A_{vul}| = 1$



Lower cutoff frequency (f_1)

Since the midband region starts at f_1 , $A_{vul} \rightarrow 1$

f_1 is the frequency at which the gain has fallen to 0.707 times the midband

value (A_{vm}) which is equal to $20 \log(1/\sqrt{2})$ or -3 dB (reduction). So f_1 is referred to as lower 3dB freq or cut off frequency.

Note: At low frequency C_C offers capacitive reactance which causes the voltage drop, due to this drop the input of the next stage reduces and hence the overall voltage gain reduces.

High Frequency Response



$$V_{O(s)} = V_{i(s)} \frac{1}{1 + j2\pi f C_{\pi} R_L}$$

$$R_L = \frac{1}{j2\pi f C_{\pi}}$$

$$\text{or } \frac{V_o}{V_i} = \frac{1}{1 + j2\pi f C_{\pi} R_L}$$

$$\text{or } A_{v(f)} = \frac{1}{1 + j2\pi f C_{\pi} R_L}$$

$$A_{v(f)} = \frac{1}{1 + j2\pi f C_{\pi} R_L} \quad \text{where } f_c = \frac{1}{2\pi C_{\pi} R_L}$$

upper cut frequency

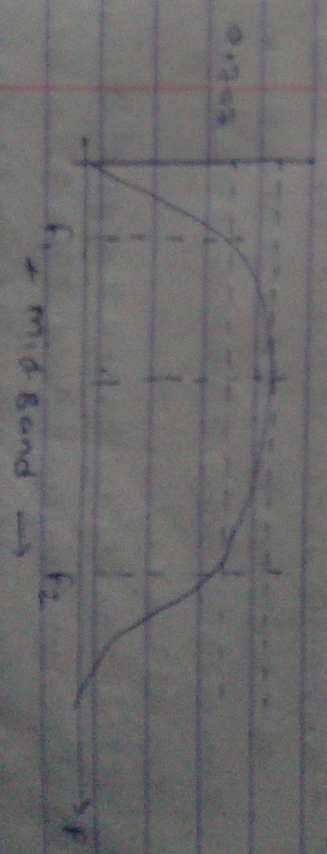
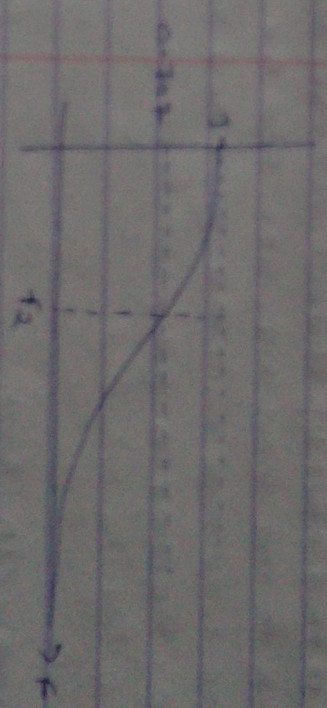
$$|A_{v(f)}| = \frac{1}{\sqrt{1 + (f/f_c)^2}}$$

$$A_{v(f)} = \frac{1}{\sqrt{1 + (f/f_c)^2}}$$

at $f=0$, $A_{vm} = 1$

at $f=f_c$, $|A_{vm}| = 1/\sqrt{2} = 0.707$

at $f_c \propto |A_{vm}| = 0$



Imp why the gain reduces at high frequency.

They stray capacitance C_s causes the output voltage of first stage to be shorted to ground and the physical capacitance of active device present in the amplifier cannot act as open ckt. They possess some reactance. Due to this, part of output voltages feed back to the input via C_{bc} and the output voltage will be grounded via C_{ce} . Hence the gain reduces.

Bandwidth (B/W):

The differences between two extreme frequencies upper cut off (f_2) and lower cut off (f_1) or it is the band of frequencies where the midband gain $A_{vm} = 1$

or, it is define as the range of frequency for which the gain falls 70.7% of its maximum value i.e. the attenuation is -3db.

(28)

i.e. gain at cut off 70.7% of A_{vm}
why cut-off frequencies are called 3db or half-power frequencies.

let V_m be the midband value,
 $\Rightarrow P_{\text{mid-band}} = \frac{V_m^2}{R}$

at cut off = $\frac{V_m}{\sqrt{2}}$

$$\text{and } P_{\text{cut off}} = \left(\frac{V_m}{\sqrt{2}}\right)^2 \cdot \frac{1}{R} = \frac{V_m^2}{2R} = \frac{P_{\text{mid band}}}{2}$$

Hence, cut-off frequencies called half-power frequencies.

So power in db;

Attenuation (power)

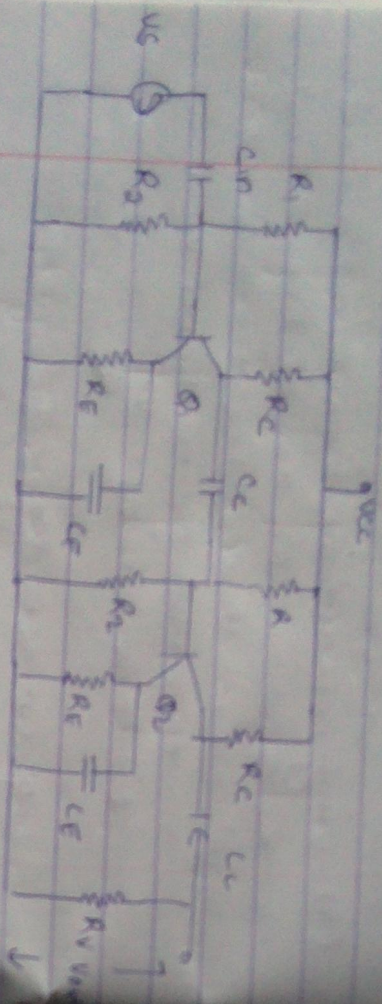
$$20 \log(P_{\text{cut off}}) = 20 \log\left(\frac{P_{\text{mid-band}}}{2}\right)$$

$$= 20 \log(P_{\text{mid-band}}) - 20 \log 2$$

$$= 20 \log(P_{\text{mid-band}}) - 3 \text{ dB}$$

Hence the gain at cut off frequencies are 3db less than the gain at mid-band range.

R-C coupled Amplifier-



C_{in} - couples the ac signal voltage to the base of Q₁

C_{out}

V_{CC} V_{EE}

So C_{in} allow ac-signal to flow into 1st CRT.

- Two transistors are identical and use a common source of voltage (power supply V_{CC})
- R₁, R₂ and R_E form biasing and stabilization CRT.

→ Here in this arrangement the signal developed at collector (P_C) of the 1st

stage is ~~coupled~~ coupled to the base of 2nd stage through C_c followed by short resistance R_E combination - voltage across C_c, V_{BE} and voltage across R_E combination (very low voltage) the voltage across R_E is very small.

Analysis: few assumptions are made:

- h_{re} very small, i.e. the voltage neglected
- β/h_{re} is very large, i.e. considered as open CRT
- R₁ and R₂ are very large than h_{ie}
- C_E very small, i.e. R_E is considered as short CRT

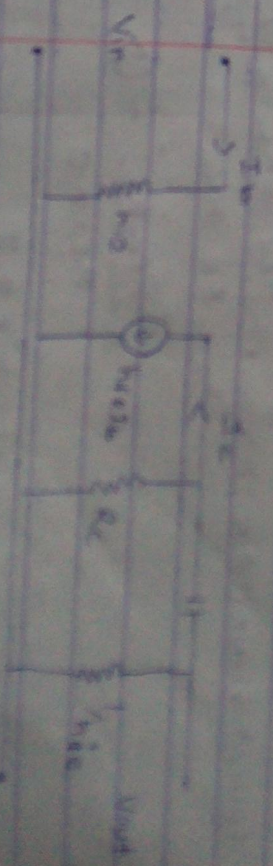


Fig. Approximate model of an R-C coupled transistor Amplifier

Mid-band Frequency Analysis

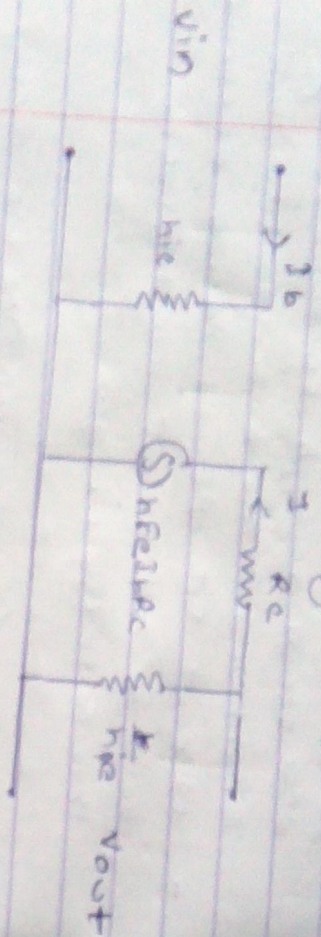


Fig: Thevenin equivalent ckt.

from above:

$$I = \frac{hfe I_b R_c}{R_c + hie} \quad \text{--- (I)}$$

$$\text{Current gain (Aim)} = \frac{I}{I_b} = \frac{hfe I_b R_c}{R_c + hie} \times \frac{1}{I_b}$$

$$= \frac{hfe R_c}{R_c + hie} \quad \text{--- (II)}$$

$$\text{Output voltage, } V_{out} = hie \times I$$

$$= hie \times \frac{hfe I_b R_c}{R_c + hie} \quad \text{--- (III)}$$

Input voltage, $V_{in} = hie \times I_b$

$$\text{Voltage gain (Avm)} = \frac{V_{out}}{V_{in}}$$

$$= \frac{hie hfe I_b R_c}{R_c + hie} \times \frac{1}{hie I_b}$$

$$= \frac{hfe R_c}{R_c + hie} \quad \text{--- (IV)}$$

from equation (II) and (IV) $A_{im} \times A_{vm}$
In this case, the impedance offered by C_c is comparable to the R_c so necessary to include in the equivalent ckt

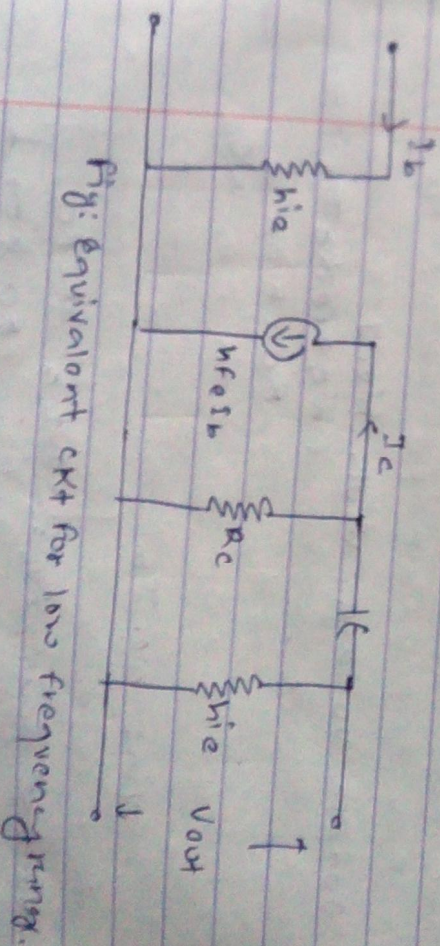


Fig: Equivalent ckt for low frequency analysis.

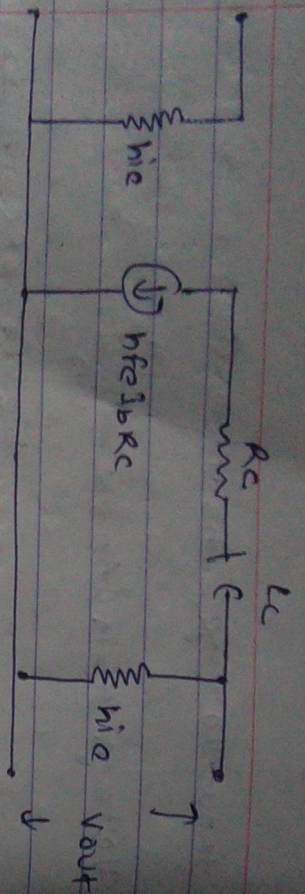


Fig: Thevenin equivalent

Now,

$$I = \frac{hfeI_b R_c}{R_c + hie + \frac{1}{j\omega C_c}}$$

$$\text{Current gain, } A_{Ib} = \frac{I}{I_b} = \frac{hfe R_c}{R_c + hie + \frac{1}{j\omega C_c}} \quad \text{--- (1)}$$

Output voltage, $V_{out} = hie \cdot I$

$$= \frac{hie hfe R_c I_b}{R_c + hie + \frac{1}{j\omega C_c}}$$

$$V_{in} = hie \cdot I_b$$

$$\text{Voltage gain, } A_{V_L} = \frac{V_{out}}{V_{in}} = \frac{hfe R_c}{R_c + hie + \frac{1}{j\omega C_c}}$$

$$\therefore A_{I_L} = A_{V_L}$$

High freq. Analysis:

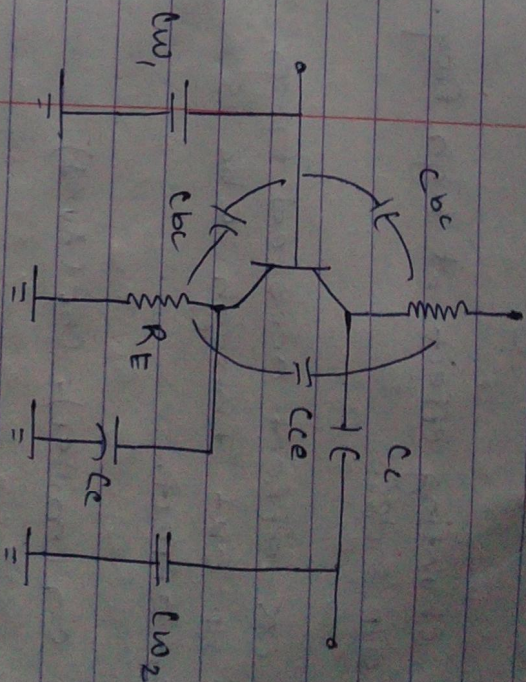


Fig: R-c coupled Amp at high freq.

$C_{cc} =$ wiring capacitance between connecting wire of CRT

$C_{bc} =$ Causes (-ve) feedback in the CRT

so gain is reduce. feedback effect

(1) with the (1) in frequency Because

(1) is freq (1) reactive impedance of capacitor.

C_{be} : Offers low impedance path at i/p side at high frequency. Reducing the i/p impedance and i/p signal.

C_{ce} - produces shunting effect at high freq. of on the o/p sides.

C_{bc} : feedback effect occurred from o/p out to i/p out through C_{bc} is called miller effect.

Statement: C_{in} (Miller): $C_{be}(A_v + 1)$

Here, C_{be} and C_{bc} may be replaced with a capacitor ' C_d ' across the input resistance h_{ie} of the transistor. i.e. the capacitance $\frac{1}{\omega C_d}$ will have appreciable

shunting effect on R_c and h_{ie} .

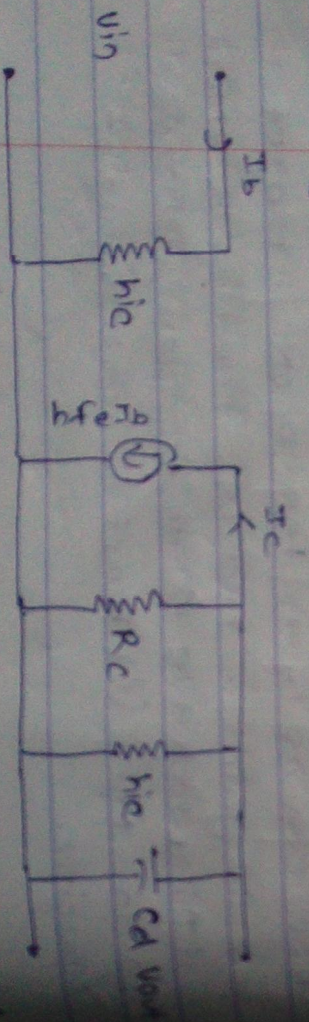


Fig: Equivalent ckt for high frequency

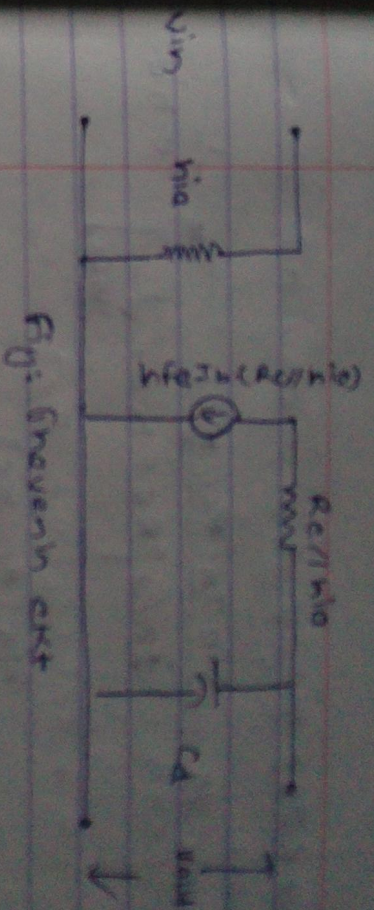


Fig: Given ckt

Now,
current, $I_c = \frac{h_{fe} I_b (R_c \parallel h_{ie})}{(R_c \parallel h_{ie}) + \frac{1}{j\omega C_d}}$

Current gain, $A_{in} = \frac{I_c}{I_b}$

$= \frac{h_{fe} (R_c \parallel h_{ie})}{(R_c \parallel h_{ie}) + \frac{1}{j\omega C_d}}$

Output voltage, $V_{out} = \frac{I_c}{j\omega C_d} + I_c$

$= \frac{1}{j\omega C_d} * \frac{h_{fe} I_b (R_c \parallel h_{ie})}{(R_c \parallel h_{ie}) + \frac{1}{j\omega C_d}}$

$$v_{in} = I_B \cdot h_{ie}$$

Now,

$$A_{vm} = \frac{v_o}{v_{in}} = \frac{h_{fe} I_B (R_c \parallel h_{ie})}{j\omega C_d [R_c \parallel h_{ie} + \frac{1}{j\omega C_d}]} \times \frac{1}{I_B \cdot h_{ie}}$$

$$= \frac{h_{fe} (R_c \parallel h_{ie})}{j\omega C_d \cdot h_{ie} (R_c \parallel h_{ie}) + \frac{1}{j\omega C_d}}$$

$$= \frac{h_{fe} R_c}{h_{ie} R_c j\omega C_d + R_c + h_{ie}}$$

So with the increase in input frequency the magnitude of the voltage gain falls.

* Lower cut-off frequency:-

The cut off frequency (f_1) may be defined as the frequency at which the $|A_{VL}|$ falls to $1/\sqrt{2}$ or 0.707 times the maximum gain at mid band range

(Avm)
Then, at $f = f_1$

$$|A_{VL}| = \frac{1}{\sqrt{2}} |A_{vm}|$$

$$\text{or, } \left| \frac{A_{VL}}{A_{vm}} \right| = \frac{1}{\sqrt{2}}$$

We have,

$$|A_{VL}| = \frac{h_{fe} R_c}{\sqrt{(h_{ie} + R_c)^2 + \left(\frac{1}{\omega C_d}\right)^2}}$$

And,

$$|A_{vm}| = \frac{h_{fe} \cdot R_c}{h_{ie} + R_c}$$

Then,

$$\frac{|A_{VL}|}{|A_{vm}|} = \frac{1}{\sqrt{1 + \left(\frac{1}{\omega C_d (h_{ie} + R_c)}\right)^2}} \quad \text{--- (A)}$$

If f_1 is the lower cut off freq. then,

$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1 + \left(\frac{1}{\omega C_d (h_{ie} + R_c)}\right)^2}}$$

Sq. on both sides,

$$\frac{1}{2} = \frac{1}{1 + \left(\frac{1}{\omega C_d (h_{ie} + R_c)}\right)^2}$$

$$\text{or, } 1 + \frac{1}{2\pi f C_c (h_{ie} + R_c)} = 2$$

$$\text{or, } \frac{1}{2\pi f C_c (h_{ie} + R_c)} = 1$$

$$\text{or, } 1 = 2\pi f C_c (h_{ie} + R_c)$$

$$\therefore f = \frac{1}{2\pi C_c (h_{ie} + R_c)} \quad \text{--- (3)}$$

from A & B

$$|A_{vH}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}} = \frac{|A_{vm}|}{\sqrt{1 + \tan^2 \theta_L}}$$

$$\text{where } \tan \theta_L = \frac{f_1}{f}$$

$$\theta_L = \tan^{-1} \left(\frac{f_1}{f} \right)$$

i.e; if $\theta_L \uparrow$ $f \downarrow$

$\theta_L \rightarrow$ phase response of the transistor.

High cut-off frequency:
The cut-off frequency ' f_c ' may be defined as the frequency at which the $|A_{vH}|$ falls to $1/\sqrt{2}$ or 0.707 times the maximum gain at mid band range (A_{vm}).

Thus at $f = f_c$

$$|A_{vH}| = \frac{1}{\sqrt{2}} |A_{vm}|$$

$$\text{or, } \left| \frac{A_{vH}}{A_{vm}} \right| = \frac{1}{\sqrt{2}}$$

Now,

$$|A_{vH}| = \frac{h_{FE} R_c}{(h_{ie} + R_c) \sqrt{1 + \left(\frac{2\pi f C_c h_{ie} R_c}{h_{ie} + R_c} \right)^2}}$$

$$\text{or } A_{vm} = \frac{h_{FE} R_c}{h_{ie} + R_c}$$

Now,

$$\left| \frac{A_{vH}}{A_{vm}} \right| = \frac{1}{\sqrt{1 + \left(\frac{2\pi f C_c h_{ie} R_c}{h_{ie} + R_c} \right)^2}} \quad \text{--- (5)}$$